

THE WEATHER AND CIRCULATION OF JULY, AUGUST, AND SEPTEMBER 1963

Dry and Cool in the East

JAMES F. O'CONNOR

Extended Forecast Branch, U.S. Weather Bureau, Washington, D.C.

PREFACE

Dr. Harry Wexler's interest in large-scale circulation and weather anomalies was well known. He was instrumental in initiating this series of articles in January 1950. Despite his numerous responsibilities, he often expressed interest, made comments and suggestions, and relied on these articles for briefing and reference to past events.

In tribute to Dr. Wexler's foresight in many areas of atmospheric science, especially in the exploitation of electronic computers, most of the illustrations in this article were computed and drawn by machine, as is true of many charts routinely prepared at the National Meteorological Center. Only labels, jet axes, and trough lines were done by hand, although the latter were specified by machine along the zero north-south components of the geostrophic flow.

1. INTRODUCTION

July, August, and September 1963 brought increasing drought to many areas east of the Rockies, from the Southern Plains northeastward, mitigated perhaps by the unseasonable coolness in this region. In some parts of the East the drought dated back to 1962 with only brief interruptions. For example, at Jackson, Miss. the 17-month period following May 1, 1962 was the driest on record.

In 1963, the first 9 months were the driest at Cleveland, Ohio since records began in 1870, and the second driest at Topeka, Kans. (only 1937 drier). During this period, Youngstown, Ohio and Corpus Christi, Tex. both reported precipitation deficiencies of 12.23 in. At Erie, Pa., precipitation for this period was only 63 percent of normal; at Concord, N.H., only 65 percent of normal; and at Dallas, Tex., only 52 percent of normal. The dryness month after month resulted in serious depletion of water reserves, crop and pasture damage, and forest fires.

2. JULY CONDITIONS

HIGHLIGHTS

Similar to earlier months of 1963 July was relatively cool in the Far West where new records for low temperature were established in parts of Oregon and northern California. It was also cool in the East, especially in the

southern Appalachians where Knoxville, Tenn. had temperatures below normal every day in July. In the Northeast a near-record cool period occurred from July 5 to 11 when minimum temperatures attained record lows on three days at Hartford, Conn. New all time records for low temperature (44° F.) for any day in July occurred at Erie, Pa., and Milwaukee, Wis., on the 9th and 10th, respectively, while on the 11th a record minimum of 49° F. occurred at Raleigh, N.C.

Heavy rains fell in the Pacific Northwest and much of the Mississippi Valley, including record amounts at Moline, Ill. (8.78 in.) and Williston, N. Dak. (6.20 in.). Near record dryness occurred in parts of Arizona, Idaho, Nevada, and Utah, as well as in Virginia and Maryland. It was also hot and dry in Texas, eastern Colorado, and parts of the upper Mississippi Valley.

JULY CIRCULATION

The circulation at 700 mb. in July 1963 (fig. 1) consisted of troughs and ridges near their normal [1] positions, with most ridges strongly amplified, and troughs less so. Of the ridges, the strongest (as reflected in height departures at 700 mb. (fig. 2)), were in the eastern Pacific and Europe, and the associated sea level anticyclones (not shown) were as much as 4 mb. stronger than normal. In the Atlantic, the subtropical High was slightly west of, and about 5 mb. weaker than, normal at sea level near the Azores.

In the eastern Pacific, 700-mb. heights averaged as much as 210 ft. above normal (fig. 2), reflecting the abnormal strength of the Pacific High, a persistent feature for five months, after its inception in March [2]. The associated strong northerly jet in the eastern Pacific (fig. 3), as in earlier months, again maintained cool weather in the Far West (fig. 4A).

Near North America, the circulation in July 1963 evolved from a strongly amplified state early in the month to a more nearly west-east flow later on. The 700-mb. westerlies between 35° N. and 55° N. in the western sector of the Northern Hemisphere declined steadily from 9.4 m.p.s. (2.5 m.p.s. above normal) in late June to 3.8 m.p.s. (3.2 m.p.s. below normal) in the period July 8-12, followed by a sharp recovery to 8.6 m.p.s. (1.4 m.p.s. above normal) during July 15-19. Thereafter

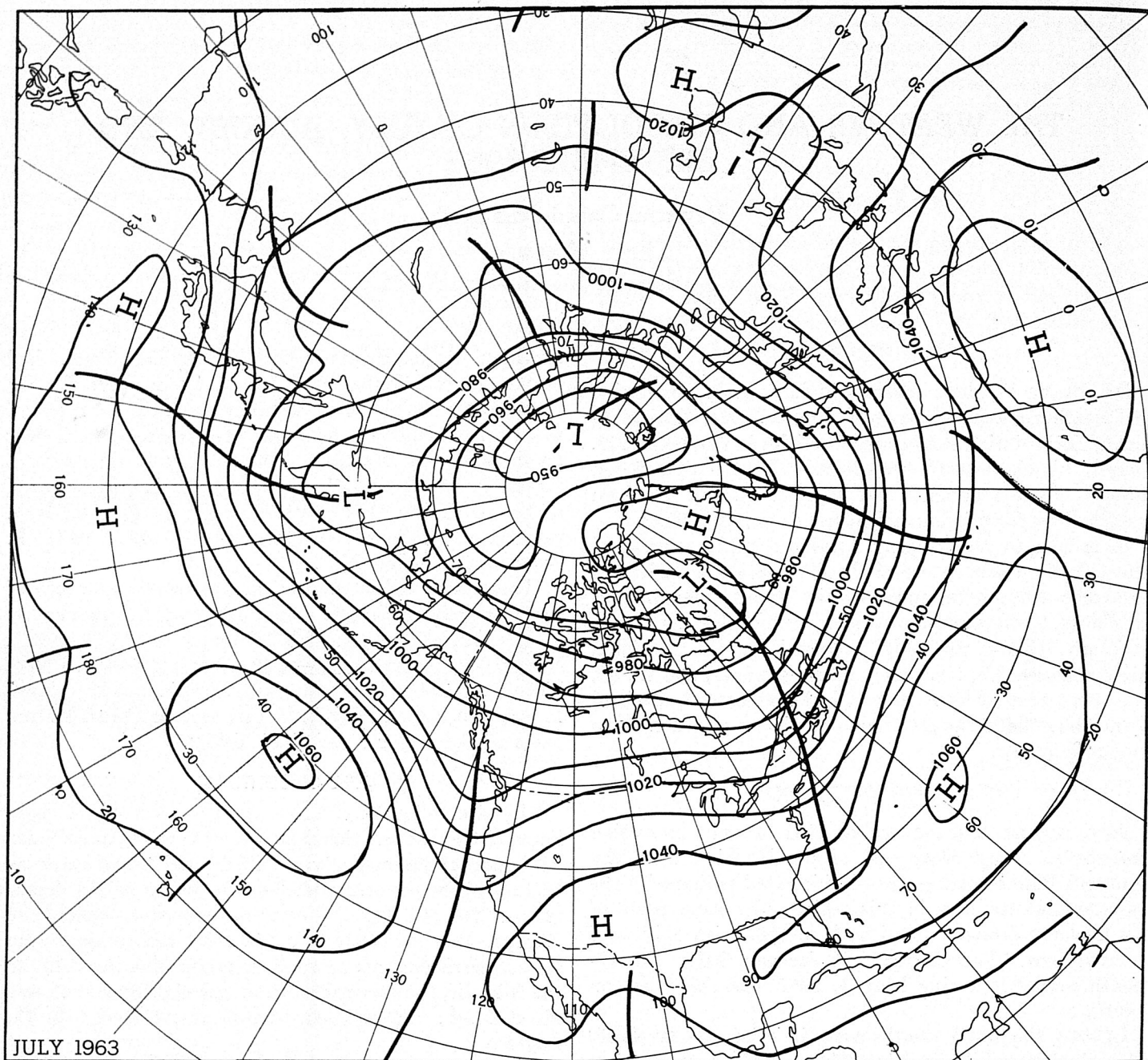


FIGURE 1.—Average 700-mb. contours (tens of feet) for July 1963. Pattern is remarkably similar to normal, although amplified.

the westerlies continued above normal but with a lowering trend.

JULY TEMPERATURE

In the United States temperatures averaged below normal in the Far West, by as much as 6.1°F . at Burns, Oreg. (fig. 4A), a new July record, under the deep coastal trough aloft. In the west-central portion of the country, above normal temperatures reached near-record values from Pueblo, Colo., to El Paso, Tex. beneath the upper ridge. The cool weather in the East averaged as much as 5.3°F . below normal at Knoxville, Tenn., for their third coldest July. These cool conditions were related

to prevailing northerly winds, which were stronger than normal west of the deep coastal trough.

Warm weather prevailing in southern Canada produced temperature averages up to 4°F . above normal in the central Provinces, accompanied by westerlies with a greater component from the southwest than usual (fig. 3). As a result cool Pacific air masses moved either north of this region, or well to the south over the eastern United States, the two preferred anticyclone tracks during the month.

JULY PRECIPITATION AND DROUGHT

In the United States, precipitation in July (fig. 4B)

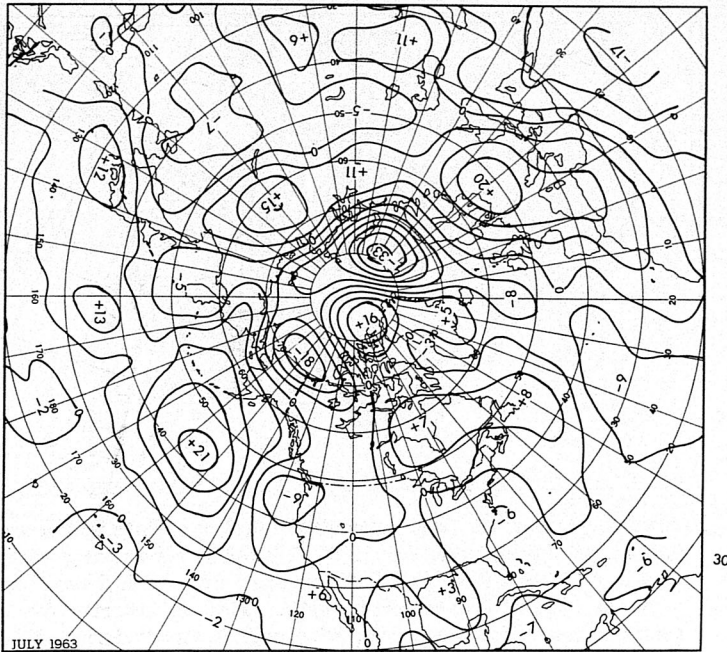


FIGURE 2.—Average 700-mb. height departures from normal (tens of feet) for July 1963. Persistent features were positive departures in eastern Pacific and negative near west coast.

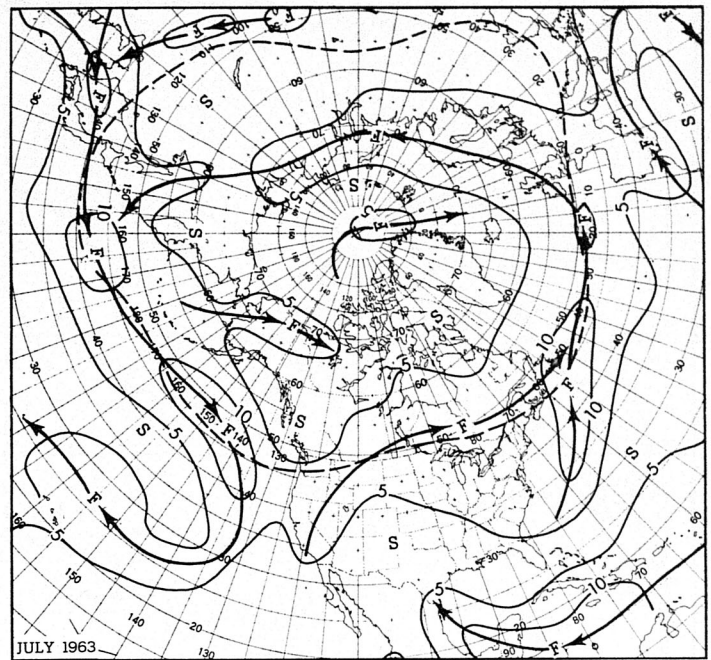


FIGURE 3.—Mean isotachs (meters per second) at 700 mb. in July 1963. Solid arrows indicate axes of maximum wind, dashed arrows the normal. Important for keeping Far West cool was northerly jet in eastern Pacific.

was heavy in parts of the Pacific Northwest, accompanied by record cloudiness in some places, notably Stampede Pass, Wash. This was due to the prevalence of cyclonic activity aloft as reflected in the negative height departures at 700 mb. (fig. 2). Heavy rains ended drought conditions in many parts of the Midwest, where as much as 6.54 in. fell at Sioux Falls, S. Dak. These rains resulted from periodic overrunning of the cooler air in the East associated with migratory cyclonic disturbances.

Very heavy rains occurred in a number of areas, for example, 10.82 in. at Chattanooga, Tenn., and 10.60 in. at Tulsa, Okla., which included a record 24-hour amount of 7.54 in. on the 27th. These rains were released in periods of upper-level cyclonic activity south of the main belt of westerlies located over southern Canada (fig. 3).

Near the east coast drier conditions prevailed as a result of subsiding northerly flow to the rear of the coastal trough. The drought in the Maryland-Virginia area is highlighted in figure 5 by the 8 days fewer than normal on which measurable precipitation fell at Richmond, Va. The total rainfall was only 0.52 in. for the driest July since records began in 1871. This drought was all the more serious because of the near record dryness in the summer of 1962 [3].

Another dry area highlighted by a deficiency of rainy days was the western Plateau, where Pocatello, Idaho had its first July without rain in 62 years, and Salt Lake City, Utah its first since 1892, while Flagstaff, Ariz. received the least rain (0.32 in.) since 1898. In Texas,

Waco had its first July since 1930 without measurable rainfall. The western drought was in accord with the average flow aloft, which was more westerly than usual, as indicated by the July height departures at 700 mb. (fig. 2).

In the State of Hawaii, the trades were stronger than normal because of the strong Pacific anticyclone, resulting in heavy rains at some windward locations.

SYNOPTIC EVOLUTION DURING JULY

In the first week the upper westerlies were strongly amplified as a deep trough aloft brought very cool weather to the Far West (average temperatures as much as 12° F. below normal at Red Bluff, Calif.), while hot weather prevailed in the Central Plains under the strong ridge aloft. In the Northeast a heat wave which reached 98° F. at Boston, Mass. on the first two days was broken by a strong cool High from British Columbia. Late in the week heavy rains developed in the Mississippi Valley as an approaching frontal disturbance caused overrunning of the cool air in the East.

During the second week the deep trough in the Far West weakened and moved inland as the westerlies straightened, advancing the cool air to the Continental Divide. Temperatures in the East were even cooler than during the preceding week, as a Hudson Bay High plunged southward near the time of the index minimum. This produced a record minimum temperature of 41° F. at Albany, N.Y. on the 9th, 17° F. below normal for the day. Heavy rains from the Mississippi Valley disturb-

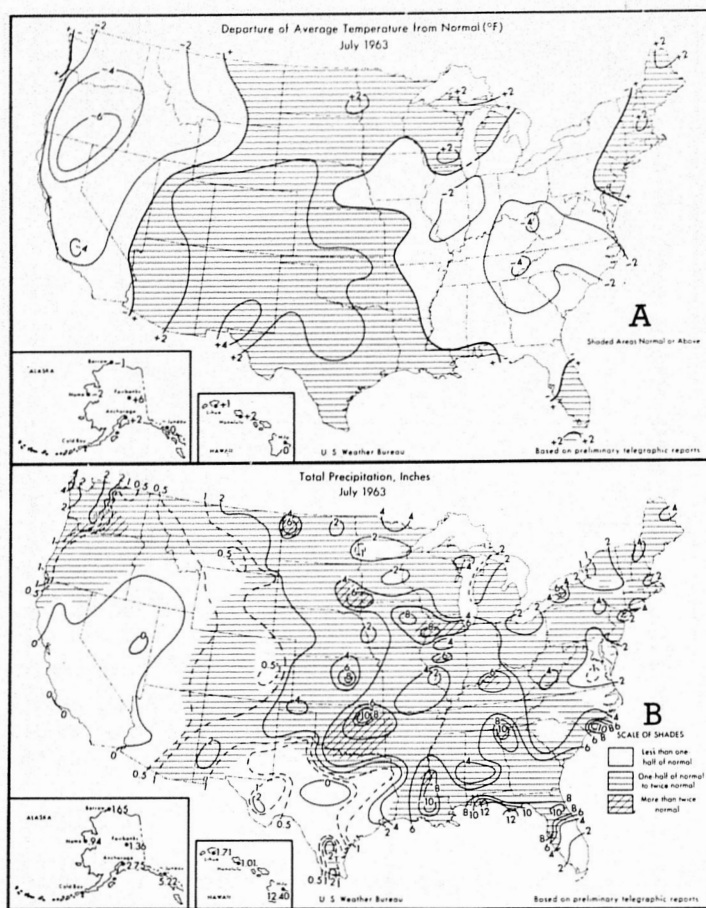


FIGURE 4.—(A) Departure of average surface temperature from normal (°F.) for July 1963. (B) Total precipitation (inches) for July 1963. (From [4].)

ance spread across the Southeast early in the week, while still another heavy rain area developed on the 12th in the central United States where a surface Low developed as a result of an eastward shift of the western trough. These rains were very beneficial, ending a drought in many sections of the Midwest.

Most of the country from the southern Rockies eastward warmed up in the third week as the strong High retrograded from the eastern Pacific and the cool trough aloft redeveloped in the Far West, although the westerlies remained relatively flat elsewhere. Of the two frontal disturbances which crossed the country that week, the first spread heavy rains across the Great Lakes Region near midweek, and the second deepened to near 1000 mb. on the New England coast at week's end, accompanied by lower temperatures and beneficial showers in many eastern sections.

A heat wave developed in the fourth week to near record intensity in some places. It spread from the southern Rockies to the Great Lakes and then eastward to the coast, with temperatures averaging 9° F. above normal at Sault Ste. Marie, Mich. and Caribou, Maine. The Southeast, however remained cool, with temperatures

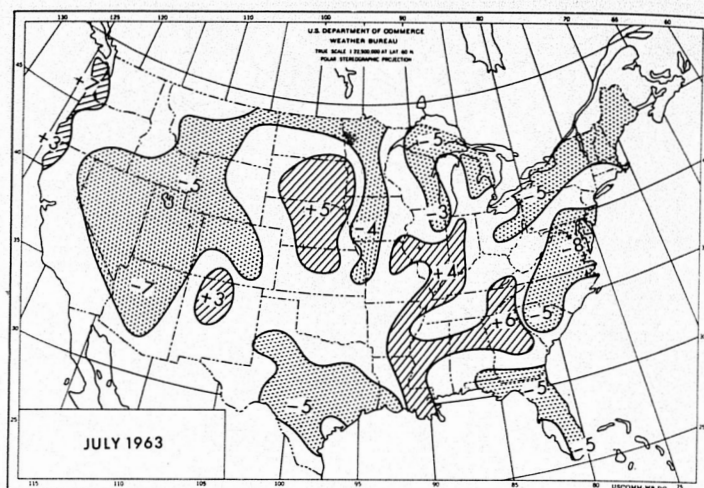


FIGURE 5.—Departure from normal of number of days with over 0.01 in. precipitation for July 1963. Stippling shows areas with 2 days or more below, and hatching, the areas with 2 days or more in excess of expected number. Most noteworthy area centered near Richmond, Va., with only 3 reported rain-days compared to a normal of 11.

averaging as much as 6° F. below normal for the week in Tennessee. This cool air was associated with a cutoff Low aloft which drifted southwestward from Pennsylvania on the 23d to Arkansas and Missouri five days later, accompanied by excessive rain in parts of the South. In the last few days, a very cool mass of air (17° F. below normal at Billings, Mont.) swept eastward, accompanied by heavy rains.

JULY TROPICAL STORMS

There were no tropical storms in the Atlantic in July, but there were three in the Pacific. Tropical storm Virginia traveled northeastward off Japan from July 4 to 9 and then became extratropical. Typhoon Wendy was detected near Guam July 9, traveled northwestward and struck Formosa on the 16th, and then moved inland over China. Typhoon Agnes was detected July 17 in the Philippine Sea. It traveled west-northwestward and hit the northern tip of Luzon, P.I., on the 20th, before entering the Asian mainland on the 22d just north of Hainan.

3. AUGUST CONDITIONS

HIGHLIGHTS

It turned warmer in the Far West in August as the coastal trough weakened. However, in the Northeast deepening of the coastal trough brought cooler weather, in some places to a record degree.

In parts of the Southwest it also turned cooler, especially in Arizona, New Mexico, and Colorado, as the drought there came to a dramatic end with the development of frequent heavy showers. Record rainfall fell in parts of Arizona, including an unprecedented rain of over 10.5 in. at Payson. At Milford, Utah, thunderstorms

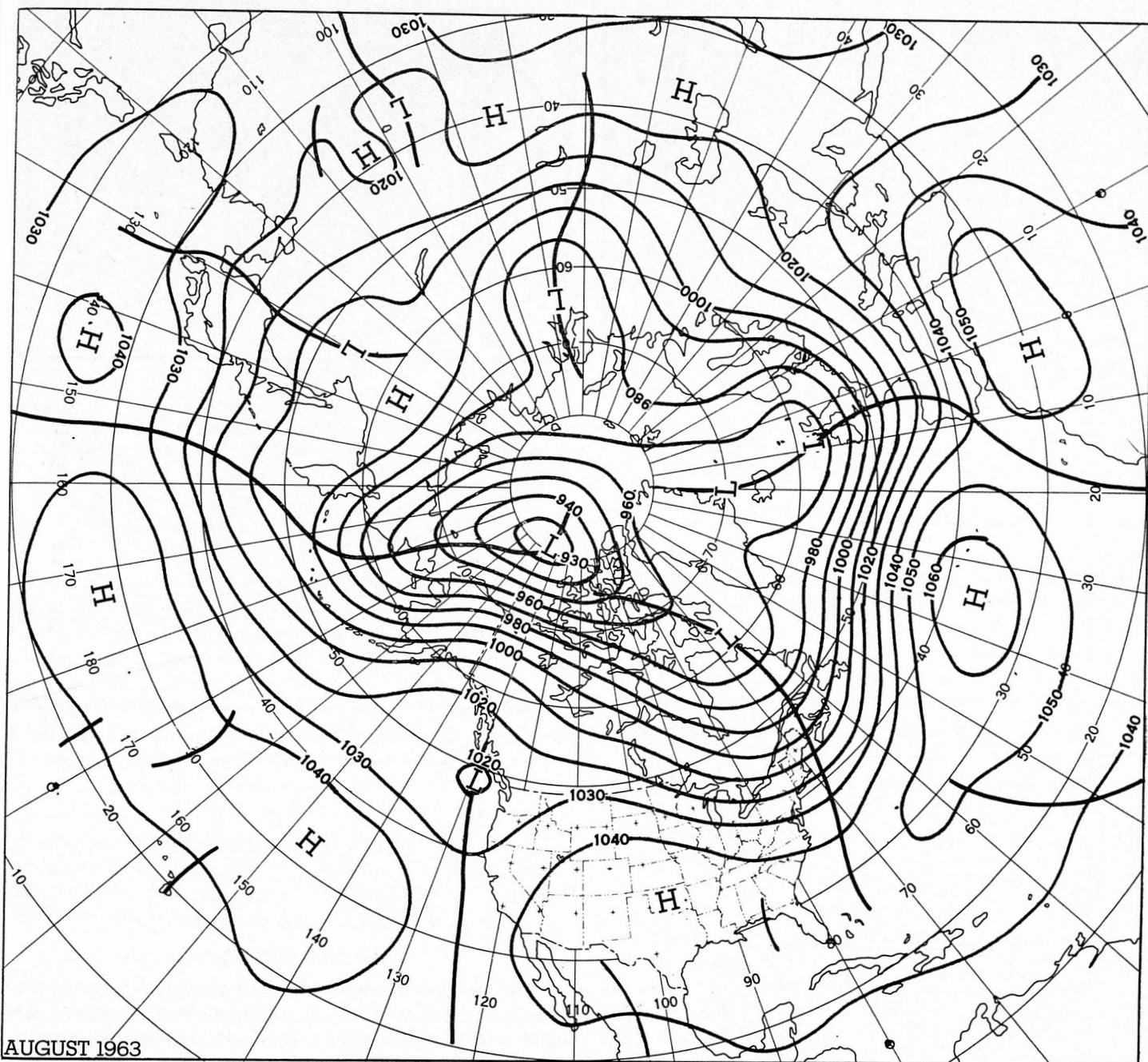


FIGURE 6.—Average 700-mb. contours (tens of feet) for August 1963. Strong northwesterly flow kept it cool in Northeast.

occurred on 17 days and at Cheyenne, Wyo. at least a trace of rain fell on 26 days. Colorado Springs, Colo. recorded 18 days of measurable precipitation.

Drought continued to be serious in various areas east of the Continental Divide. At Dallas, Tex. this was the driest August on record, with only 0.02 in. of rain. In parts of the Atlantic Seaboard it was the driest August since 1930.

AUGUST CIRCULATION

After five consecutive months of relatively persistent circulation patterns at 700 mb., similar to those of July (fig. 1), pressure falls north of Hawaii in August weakened the previously strong Pacific anticyclone. This was

accompanied by weakening of the mean trough at 700 mb. along the west coast of North America. Meanwhile a strong ridge developed over Alaska and western Canada (fig. 6). To the north, strong deepening occurred over the Arctic Ocean, with maximum anomaly of 320 ft. below normal (fig. 7). As a result a strong mean jet developed along the Arctic coast of Alaska (fig. 8), which favored deepening of the trough near the east coast of North America. The wave pattern over North America reached its greatest amplitude near mid-month, after which flattening occurred.

Farther east, a compatible amplification at 700 mb. was reflected in strong deepening of troughs near the European

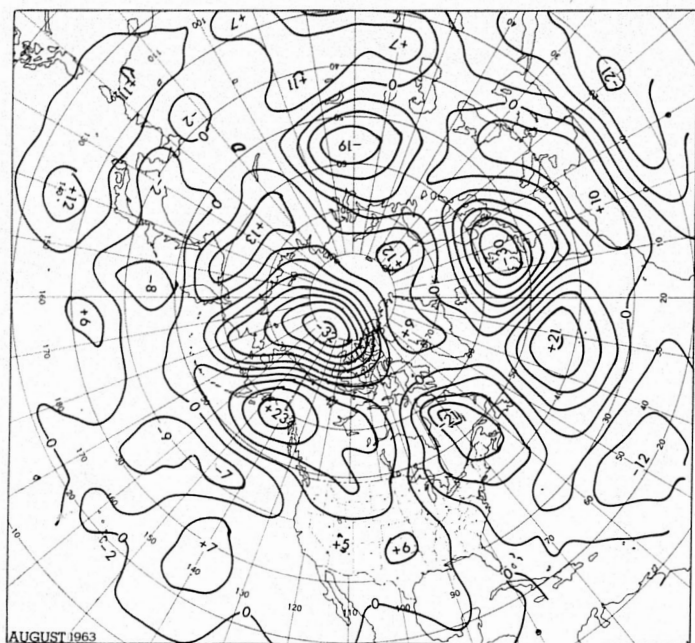


FIGURE 7.—Average 700-mb. height departures from normal (tens of feet) for August 1963. Strong gradient between the Gulf of Alaska and the Arctic Ocean reflects abnormal strength of westerlies.

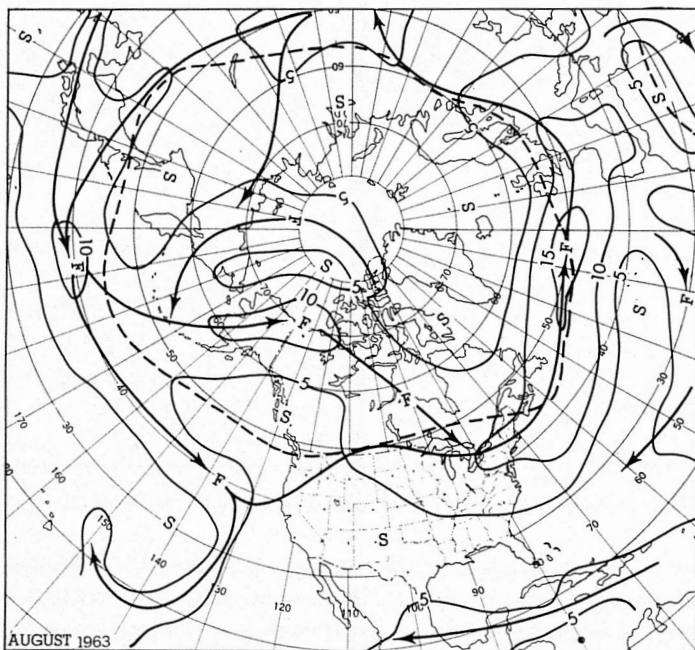


FIGURE 8.—Mean isotachs (m.p.s.) at 700 mb. in August 1963. Strong speed maximum near the Arctic coast of Alaska helped keep eastern trough deep.

coast and in Siberia and intensification of ridges in the Atlantic and eastern Europe.

The mid-latitude westerlies at 700 mb. in the western sector of the Northern Hemisphere declined to a minimum

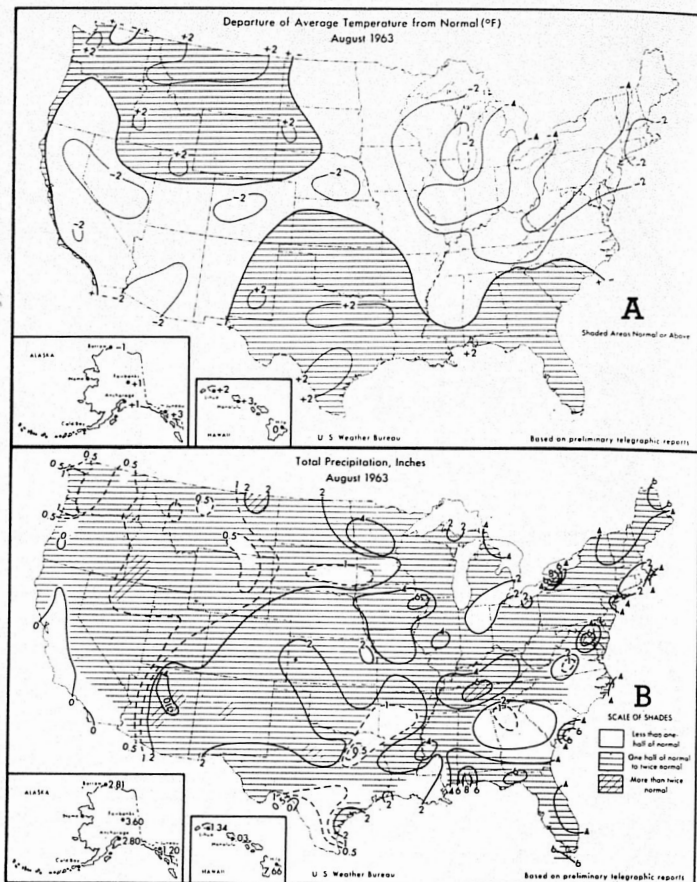


FIGURE 9.—(A) Temperature anomaly ($^{\circ}\text{F.}$) and (B) total precipitation (in.) for August 1963. (From [4].)

of 5.1 m.p.s. (1.7 m.p.s. below normal) during August 8–12, then rose to a maximum of 8.5 m.p.s. (1.5 m.p.s. above normal) during August 20–24, followed by another decline to a normal 7.1 m.p.s. at month's end.

AUGUST TEMPERATURE

August temperatures (fig. 9A) averaged warmer than normal in the northern Rockies, under the upper ridge, and also in the southern Plains in association with the anticyclone aloft (fig. 6).

California and Nevada were not as cool as in July, but nevertheless it was the sixth consecutive month of below normal temperature in some places, notably Red Bluff, Calif. Over the southern Rockies and parts of the adjacent Plains, it turned much cooler as a result of the persistent cloudiness and showers.

August was unusually cool in the Northeast, as indicated by the lowest average monthly temperature on record at Youngstown, Ohio and Buffalo, N.Y. Youngstown's departure from normal (5.2°F.) was equal to about two standard deviations [5]. Buffalo's departure (4.1°F.) was slightly less. Numerous record daily minimum temperatures occurred during the cool spells of August 14–18, 24–28, and 30–31, and some were the lowest ever recorded in August, notably 41°F. at South Bend, Ind. on the 18th.

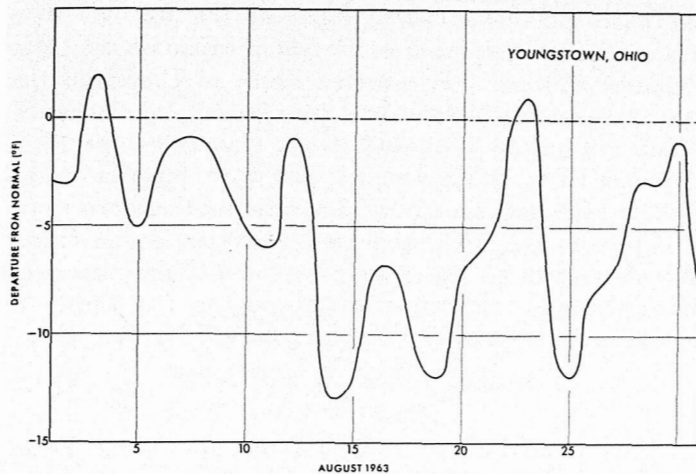


FIGURE 10.—Departure from normal of average daily temperature (°F.) in August 1963 at Youngstown, Ohio. Repeated intrusions of cool air occurred without intervening above-normal temperatures.

In some cities this was the first August when the temperature failed to exceed 85° F.; e.g., at Akron, Ohio, in 76 years of record. Record low maxima were also common, especially on the 18th at Kansas City, Mo. (65° F.) and on the 19th at Des Moines, Iowa (58° F.).

The cool weather in the East began about August 10 with the first of five outbreaks of cool air from Canada. These were associated with an unusual path of Highs, from northwestern Canada across Minnesota through the Ohio Valley. Such a track is more characteristic of mid-winter than August [6], but was in accord with the strongly amplified northerly current that prevailed this month at upper levels (figs. 6, 7, 8). The successive cool spells, as observed at Youngstown, Ohio are shown in figure 10.

AUGUST PRECIPITATION AND DROUGHT

Precipitation in August (fig. 9B) was heavy in Arizona, New Mexico, and Colorado, in contrast with the near-record dryness in July. In a gross sense, this rainfall was related to a persistent trough in the easterlies over Mexico (fig. 6) into which moisture from the Gulf was repeatedly injected by a southeasterly current. This current was stronger than normal as a result of the enhanced gradient between the strong High over the Southern Plains and abnormally low heights over Mexico.

In the Northwest most precipitation was related to the gyrations near the coast from August 10 to 25 of an upper-level Low which was blocked by the strong ridge to its north.

East of the Rockies most heavy precipitation was localized and resulted from disturbances of the synoptic rather than the planetary scale. There were fewer than the usual number of days of measurable rainfall (fig. 11), as might be expected in the prevailing northerly current aloft west of the deep trough near the east coast. An

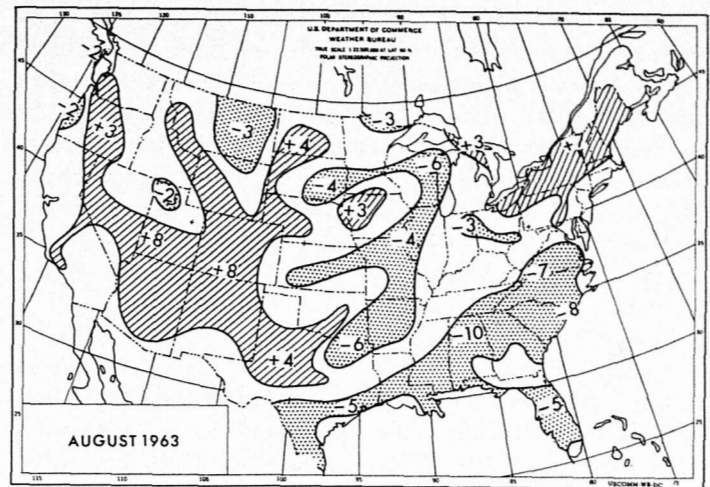


FIGURE 11.—Departures from normal of number of days with measurable precipitation for August 1963. Shading as in figure 5. Noteworthy was the deficiency of 10 days at Birmingham Ala.

exception was upper New York State and New England, where rain-days were more numerous than usual, and produced heavy accumulations, notably at Buffalo, N.Y. (8.04 in.) and Caribou, Maine (6.39 in.). This was reflected in large-scale cyclonic relative vorticity of the August circulation (not shown) and also in the curvature of negative height departures (fig. 7).

Drought became increasingly serious in many areas east of the Rockies and was associated with subsiding northerly flow between the western ridge and the trough near the coast. Deficiencies of precipitation in August lengthened the period of consecutive months of dryness at a number of cities, including Concord, N.H. (10 months), Erie, Pa. and Cleveland, Ohio (8), San Antonio, Tex. and Albany, N.Y. (6). In addition this was the seventh month of deficient precipitation this year at Marquette, Mich. and Dodge City, Kans. A rainfall of only 0.56 in. was the second lowest for any August at Chattanooga, Tenn., while at Birmingham, Ala., all the rainfall (1.53 in.) fell in 6 hours on the 13th.

SYNOPTIC EVOLUTION DURING AUGUST

During the first week an upper-level High prevailed over the Southern Plains, with flat westerlies near the Canadian Border. At the surface a weak Pacific High crossed the country, preceded by a front which became stationary from Colorado eastward. Showers and cool, cloudy weather occurred daily in the moist tongue from Arizona to Colorado. In the Northeast, Buffalo's disastrous 3.88 in. of flooding rain in 5 hours on August 7 was associated with a weak occluded front which produced only moderate amounts elsewhere.

In the second week, amplification of the ridge over the Rockies was accompanied by warming to as much as 13° F. above normal in some sections and by considerable

thunderstorm activity. In the East the first cool High from Canada arrived on the 10th, followed by a storm which became abnormally deep as it moved from the Dakotas on the 11th to Newfoundland on the 14th. In its wake another cool Canadian High lowered temperatures from the Divide to the east coast as much as 13° F. below normal on the 14th. This was preceded by heavy rains. On the 15th Pittsburgh, Pa. had its lowest August minimum (45° F.) since records began in 1870.

In the third week a shift of the Low and trough inland ended the heat and brought below normal temperatures to the Northwest. Excessive rains fell in the Southwest, notably near Prescott, Ariz., on the 16th and 19th with flood damage. East of the Rockies the third Canadian cool air mass lowered temperatures to 19° F. below normal at Des Moines, Iowa on the 18th with a maximum temperature of only 58° F., a new record. Late in the week, the upper Midwest warmed to well above normal. Heavy rains from a frontal wave in the Plains on the 18th totaled nearly 2 in. at Kansas City but diminished as the disturbance approached the east coast. However near Washington, D.C. a disastrous total of 6.54 in. fell on August 19-20, and produced considerable flood damage in Alexandria, Va.

In the fourth week the western ridge at 700 mb. shifted eastward with considerable warming in the Plains as the eastern trough moved off the coast. It continued cool in the Far West and in the extreme East where another cool outbreak on the 24th was due to a strong High over southern Hudson Bay. On August 27-28 a disturbance from the West advanced to the Ohio Valley, preceded by a record temperature of 107° F. at Little Rock, Ark., and accompanied by heavy rains in some places including Nashville, Tenn., where 4.10 in. fell on the 28th. In the last few days another cool mass of air advanced to the coast, associated with a High from Alberta. Heavy rains continued in the Southwest, where 2.87 in. fell on the 30th at Abilene, Tex. and 1.79 in. on the 31st at Flagstaff, Ariz.

AUGUST TROPICAL STORMS

There were two hurricanes in the Atlantic in August. Both were steered by the strong southwesterly flow east of the deep coastal trough (fig. 6) and neither threatened the mainland. Arlene was detected on August 2 east of the Windward Islands but disappeared near Antigua on the 5th. On the 8th it was again detected southwest of Bermuda, which it brushed on the 9th while traveling northeastward with hurricane intensity. It became extratropical on the 11th east of Newfoundland. Hurricane Beulah was detected on the 21st east of the Leeward Islands. It traveled northward to east of Newfoundland on the 28th, when it became extratropical.

In the western Pacific there were four typhoons. Bess was located on July 27 near Guam and became a typhoon in the Philippine Sea on August 3. It moved north-

westward, striking southern Japan on the 9th, and then weakened to a depression in the Sea of Japan on the 11th. Typhoon Carmen was detected south of Guam on the 7th, traveled northwestward across Luzon and the South China Sea on the 14th, and struck Hainan on the 16th. Typhoon Della, which was detected near Okinawa on the 25th, moved northeastward along the southeastern coast of Japan on the 28th, and then weakened to an extratropical system on the 30th. Typhoon Elaine was near Marcus Island when first discovered on the 25th. It became extratropical on the 28th near 40° N., 170° E.

4. SEPTEMBER CONDITIONS

HIGHLIGHTS

Drought was severe over a large area from Texas across the Middle Mississippi and Ohio Valleys in September. It was the driest September on record at Dayton, Ohio (0.27 in.) and Indianapolis, Ind. (0.24 in.). Parts of the Northeast experienced the 11th consecutive month of below normal precipitation, for example, Scranton, Pa., and Concord, N.H. It was the driest year to date at Cleveland, Ohio and the second driest at Topeka, Kans., and Dallas, Tex. The Red River was at its lowest stage in 52 years at Alexandria, La.

It was the wettest September on record at some widely scattered locations, including San Diego, Calif. (1.90 in.), Ely, Nev., (2.18 in.), Port Arthur, Tex., (18.15 in.) and Key West, Fla. (18.45 in.). The latter pair of cities owed most of their rainfall to tropical disturbances.

In the West, the warming trend of August continued and encompassed the Southwest as well. It was the warmest September on record at many cities including Sheridan, Wyo., Burns, Oreg., Seattle, Wash., Boise, Idaho, Glasgow, Mont., and Los Angeles, Calif. The month was climaxed by an unprecedented heat wave in the last week during which new record high temperatures for so late in the season occurred on as many as four days, including 111° F. at San Diego on the 26th, the highest ever recorded there.

In the East it was the coolest September on record at some cities including Burlington, Vt., Philadelphia, Pa., Norfolk, Va., and Wilmington, N.C. In the Northeast an unusually early killing frost on September 14 resulted in the shortest growing season on record at Albany, N.Y. This reflected the persistence of unseasonably cool weather since May.

SEPTEMBER CIRCULATION

In September, sharply declining pressures in the Gulf of Alaska and westward across the Aleutians to Kamchatka, were accompanied by strengthening of the subtropical High in the Central Pacific (fig. 12) and of the associated westerlies in the Pacific at mid-latitudes (fig. 13). North of Alaska, the deep Low and jet axis of August (fig. 6) gave way to rising pressure over the Beaufort Sea. Over North America a strong ridge and anticyclone aloft developed in response to the deep Gulf of Alaska Low.

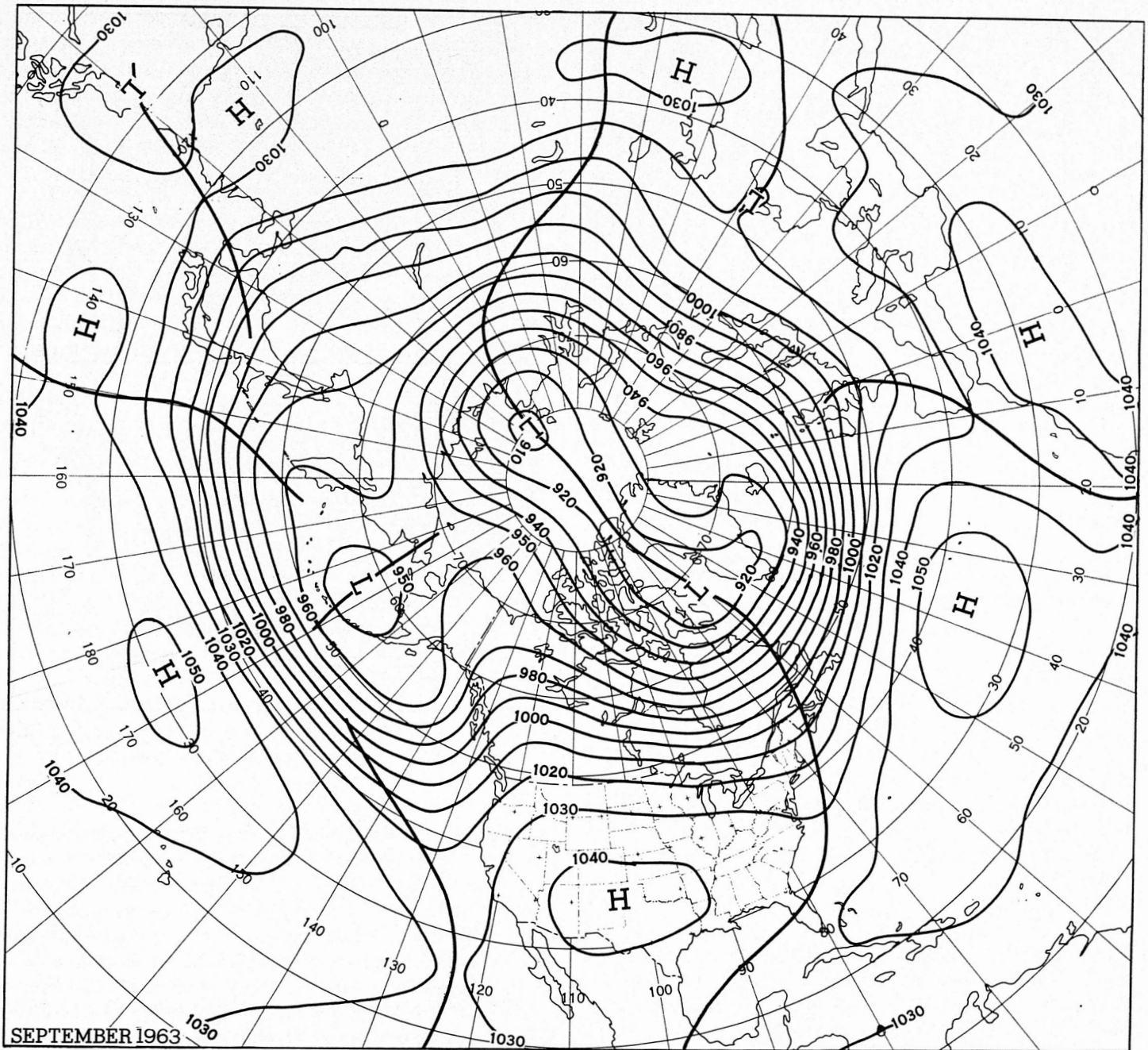


FIGURE 12.—Average 700-mb. contours (tens of feet) for September 1963. Strong ridge was related to warmth in West.

Eastward across the Atlantic and Europe, the troughs along the coasts of North America and Europe weakened at mid-latitudes, but continued strong at lower latitudes. Over Greenland and Iceland large height falls produced an abnormally strong Icelandic Low. The associated belt of westerlies north of the strong Azores High extended across northern Europe.

Over North America, the strong ridge in the West weakened gradually during the first three weeks as the deep trough off the coast moved over California, while the anticyclone over the United States drifted toward the mid-Mississippi Valley. In the last week the Cali-

fornia trough retrograded, while the High in the central United States shifted westward and intensified over Utah.

The mid-latitude westerlies at 700 mb. in the western sector of the hemisphere steadily strengthened during the month from a normal speed of 7.2 m.p.s. to 10 m.p.s. (1.4 m.p.s. above normal) near month's end.

SEPTEMBER TEMPERATURES

In the United States (fig. 15A) temperatures in September averaged warmer than normal west of the Mississippi River under the strong ridge and anticyclone aloft

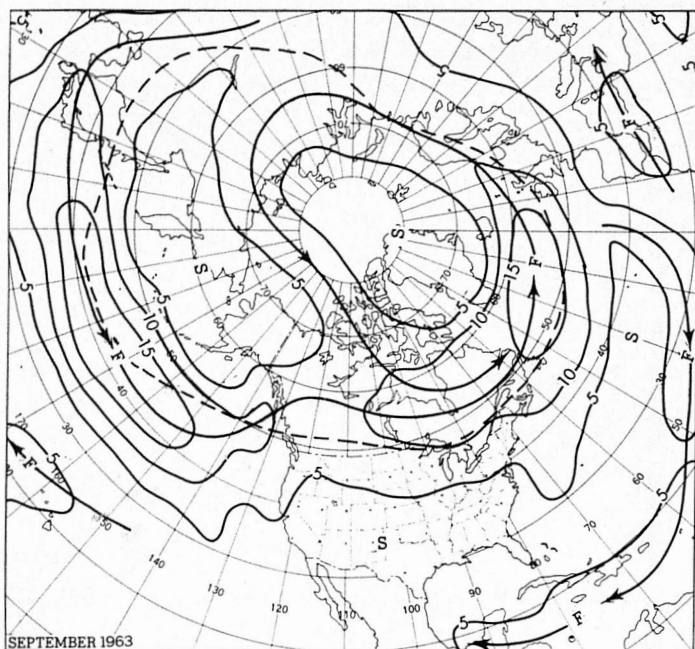


FIGURE 13.—Mean isotachs (m.p.s.) at 700 mb. for September 1963. Unusual northern position of jet axis diverted disturbances far to the north.

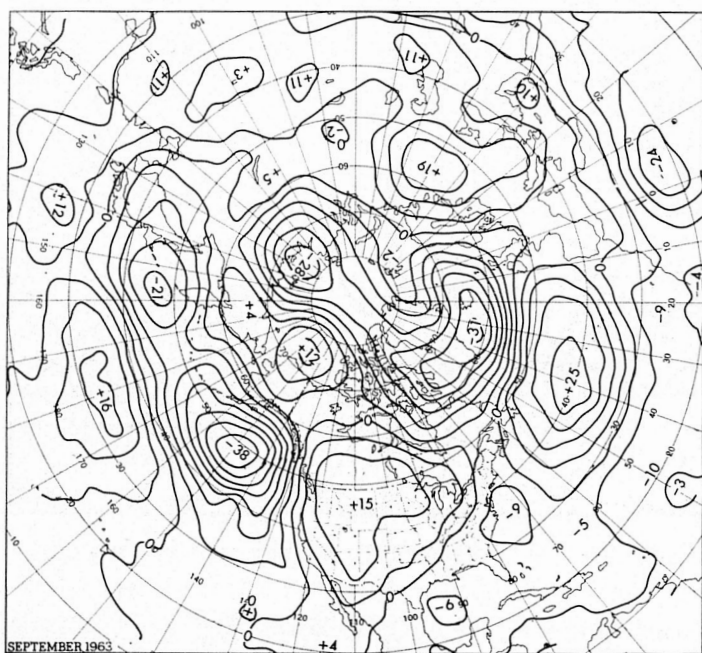


FIGURE 14.—Average 700-mb. height departures from normal (tens of feet) for September 1963. The northeasterly geostrophic flow indicated by the departures in the East contributed to the drought there.

(fig. 14). The record heat wave in the West during the last week was associated with the development of an unusually strong anticyclone aloft over the Rockies. In addition to the transport of warm air northward by strong

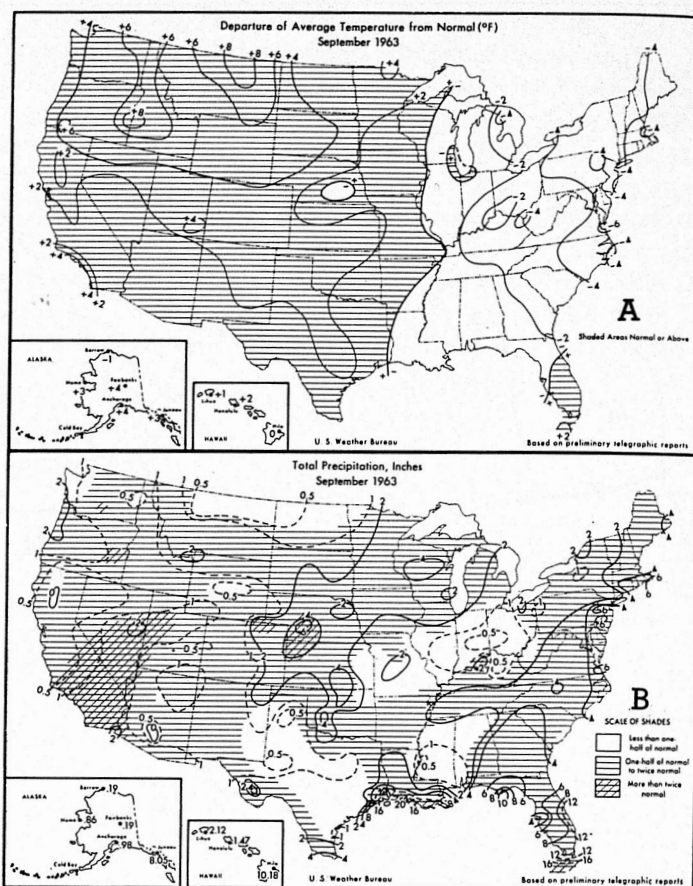


FIGURE 15.—(A) Temperature anomaly ($^{\circ}\text{F.}$) and (B) total precipitation (in.) for September 1963. (From [4].)

southerly flow near the coast and the blocking of cool Pacific air from entering the country, subsidence was an important factor. The dynamic warming and drying was also reinforced by foehn regimes. This was manifested in easterly winds at Los Angeles, Calif., at the surface as well as aloft, during an unprecedented series of five consecutive days with temperatures over 100°F. Foehn conditions were also important on the eastern slopes of the Rockies. Temperatures at Glasgow, Mont., aided by dynamic warming in the westerlies north of the strong Basin High, averaged 8.5°F. above normal for the month (more than 2 standard deviations).

East of the Mississippi River it was cooler than normal in September in connection with persistent northerly flow. Its abnormal strength is indicated in the geostrophic flow implied by the height departures at 700 mb. (fig. 14). Probably the coolest area, relative to normal, was near Norfolk, Va., which averaged 5.0°F. below normal (about 2.5 standard deviations) for the coldest September since records began in 1871.

New low temperature records were established during the four principal cool spells of September 5–6, 14–15, 22–25, and 29–30. These cool periods were associated with an anticyclone track from northwestern Canada southeastward across the Northeast which was more

characteristic of cooler months but in accord with the amplified northerly flow over eastern North America. Some daily temperatures reached new lows for the entire month of September, notably 23° F. at Pittsfield, Mass., 25° F. at Burlington, Vt., and 37° F. at Richmond, Va., on the 24th, and 35° F. at Philadelphia, Pa. on the 25th.

SEPTEMBER PRECIPITATION AND DROUGHT

This was one of the wettest Septembers ever recorded in parts of the Far West from southern California to Idaho (fig. 15B). The geostrophic flow implied by the 700-mb. height departures (fig. 14) indicates considerably augmented southerly flow over that region, which carried moisture northward. On the synoptic scale the biggest rain producer was a deep upper-level cyclone which moved from California to the Central Plains during September 17-22 and spawned tropical storm Katherine near Baja California. Heavy rains in the Central Plains, including 6.03 in. (over three times the normal) at North Platte, Nebr., and 4.84 in. (almost four times the normal) at Goodland, Kans., were released by weaker upper-level disturbances.

Elsewhere in the nation it was very dry except for short periods of excessive rains associated with tropical storms. In the East there were three principal rainy periods during the cold outbreaks of September 4-5, 14-15, and 29-30. About 80 percent of the total monthly rainfall (4.90 in.) at Wichita, Kans. fell during or prior to the first cold outbreak, and 75 percent of the total (6.84 in.) at Norfolk, Va. was associated with the second, while 92 percent of the total (6.86 in.) at Rome, Ga. was associated with the third outbreak. The month's total rainfall of 6.44 in. at Philadelphia, Pa., consisted of almost equal amounts released on September 3, 16, and 29. These heavy rainfalls were associated with upper-level Lows of small scale and were the exceptions rather than the rule in the East, where the overall character of the rainfall was light this September.

The drought was aggravated in many areas in September by the abnormal strength of the upper-level anticyclone (fig. 12). The abnormally strong northerly flow over the East precluded any large-scale introduction of moisture into the East. The persistently strong High also diverted rain-producing disturbances far north of normal as the jet stream (fig. 13) made a corresponding shift from its normal location over the upper Great Lakes. Further aggravating the dryness was large scale subsidence which inhibited cloudiness and favored increased evaporation of surface moisture.

The resulting drought is portrayed in figure 16 in terms of departures of the number of days of measurable rain from normal. In these terms, the drought was most critical in the Ohio Valley, where Indianapolis, Ind. had rain on only one day, totaling 0.24 in., compared with an expected 9 days with 3.24 in. Some cities with six days less than the normal number were St. Louis, Mo., Marquette, Mich., Columbus, Ohio, and Daytona Beach, Fla.

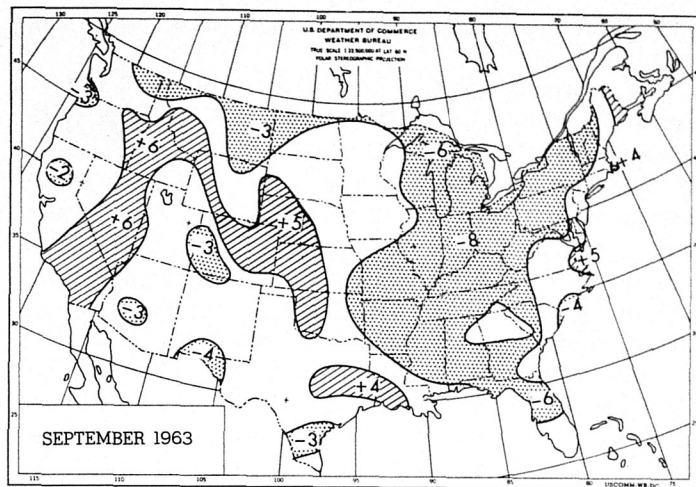


FIGURE 16.—Departures from normal of number of days with measurable precipitation for September 1963. Shading as in figure 5. Deficiency of 8 days at Indianapolis, Ind. reflects less than 1 hour of rain for the entire month.

SYNOPTIC EVOLUTION IN SEPTEMBER

During the first week a strong High aloft over the Southern Plains with a ridge to the Northwest spread showers and warmer air over much of the West. Texas was dry and hot with a record 103° F. at Dallas on the 5th. Northerly flow aloft kept the East cool, reinforced by a cool outbreak which produced record low temperatures in New York on the 5th.

In the second week the average circulation and temperature pattern changed but little. The heat in the West reached a record 93° F. at Spokane, Wash. on the 10th. It became even cooler in the East on the 12th as another Canadian High moved across the Great Lakes, preceded by showers over many areas. At Louisville, Ky., a major part of the month's rainfall of 2.58 in. fell on the 12th. Record low temperatures occurred from Michigan eastward on the 14th, and subfreezing readings occurred in Pennsylvania, New York, and New England. Portland, Maine recorded 28° F., ending the shortest growing season on record.

In the third week a deep cutoff Low moving slowly across the central Rockies brought heavy rains to the West and North Central States, while a strong upper High over the mid-Mississippi Valley brought extreme dryness from that region eastward. All across the South heavy tropical rains were a feature of the week. In the Southwest, Yuma, Ariz., received 2.47 in. on the 17th, the greatest 24-hour amount in 24 years, from tropical storm Katherine. In the Gulf area, Port Arthur, Tex. received 16.26 in. from hurricane Cindy from the 16th to the 19th, and Key West, Fla. received about 9 inches from another tropical disturbance on September 19-20. Norfolk, Va. recorded 5.20 in. in 24 hours on September 15-16; while farther north along the coast heavy amounts, including 2.79 in. at Nantucket, Mass., were general as

a result of a coastal disturbance associated with a Low aloft.

Temperatures cooled to below normal in the Far West due to the deep Low aloft, and it remained cool in the extreme East, reinforced by another cool outbreak on the 21st. In the Central States it was very warm on the western side of the upper anticyclone, with temperatures reaching the 90's.

In the last week of September a strong upper anticyclone developed over the Rockies, accompanied by a historic heat wave in the West and North Central States. Average daily temperatures were as much as 28° F. above normal with maxima as high as 110° F. at Los Angeles, Calif. on the 26th. Record high temperatures for so late in the year continued over a large part of that region on September 27–28.

In the East the strong High from Canada and accompanying cool spell which started on the 20th lingered until the 26th. On September 24–25 record low temperatures for the month or for so early in the season occurred in the Northeast, while farther south new records for those dates were common.

About the 27th, another cold High plunged into the Midwest from British Columbia. This was accompanied by heavy rains in parts of the East on September 27–29, and especially in the South as a deep Low aloft over that area merged into a polar trough associated with the cold outbreak. This was the first outbreak to affect Texas, where Lubbock reported a record 38° F. on the 30th.

SEPTEMBER TROPICAL STORMS

There were three hurricanes in the Atlantic and Gulf of Mexico in September, not counting Flora which was first observed on September 30, and later devastated part of Cuba and Haiti in October. Hurricane Cindy was detected in the Gulf of Mexico early on September 16 about 150 mi. south of Port Arthur, Tex. It moved northward and crossed the coast near Port Arthur on the 17th, dissipating over southern Texas during the next two days. Heavy flooding from torrential rains occurred in the Sabine-Neches area of Jefferson County, Tex., near the Louisiana border. Hurricane Debra was first observed on September 21 in the Atlantic near 23° N., 49° W. It drifted slowly northeastward to become a weak extratropical system on the 24th. Hurricane Edith was detected on the 24th about 150 mi. east of Barbados and the Windward Islands. It traveled northwestward across the Dominican Republic on the 27th and later weakened and merged with an extratropical disturbance east of the Bahamas near month's end.

In the western Pacific, there were four tropical storms, excluding typhoon Judy which was first observed on September 30. Typhoon Faye, detected in the Philippine Sea north of Yap Island on September 1, moved northwestward across Luzon Strait and weakened over the Gulf of Tonkin on the 8th. Typhoon Gloria was first observed

on September 5 west of the Marianas Islands. It then moved northwestward, brushing the northern tip of Formosa on the 11th, and entered China on September 12. Tropical storm Hester was located north of the Caroline Islands on the 8th as a weak depression drifting northwestward. It passed through the Marianas Islands and intensified to a storm in the Philippine Sea on the 11th, but dissipated next day. Tropical storm Irma was first observed on the 17th north of the Carolines. It drifted westward into the Philippine Sea and weakened to a depression on the 19th.

In the eastern Pacific four tropical storms were detected in September. On the 12th, tropical storm Irah was observed near 18° N., 125° W. It gradually weakened as it moved westward, but brought about 1.50 in. of rain to Hawaii on the 17th. Jennifer was detected on September 13 near 18° N., 113° W. and disappeared from that area on the 17th. Katherine appeared near Baja California and moved inland on September 17 about 200 mi. southeast of San Diego, Calif., bringing heavy rains to that region. Lillian was observed near 17° N., 102° W. on September 24 drifting northward off the coast of Mexico. It moved inland on September 28.

ACKNOWLEDGMENTS

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